Rigorous Undergraduate Chemistry Programs

The ACS approval program is intended to promote the development of excellent undergraduate programs that, according to the ACS Guidelines, “offer their students a broad-based and rigorous chemistry education that provides them with the intellectual, experimental, and communication skills to participate effectively as scientific professionals.” One hallmark of an excellent program is that it is rigorous; however, articulating a clear description of what constitutes a “rigorous” program is surprisingly challenging.

In academic settings, the term “rigorous” is usually defined in a context-specific way. Thus, the goal of this supplement is to elaborate the qualities that CPT seeks as evidence for rigor in periodic reviews. In the CPT vision, a rigorous undergraduate program is comprised of an integrated series of experiences that demonstrate the systematic application of fundamental principles to understanding chemical systems. Hence, in evaluating undergraduate programs, CPT seeks as evidence for rigor certain attributes to be manifest in the curriculum, in faculty instructional approaches, in student competencies, and in the assessment of student learning as described below.

Characteristics of the Curriculum in Rigorous Undergraduate Programs

A rigorous undergraduate curriculum is one that provides both foundation and in-depth course work that

• is appropriately balanced in breadth of content coverage and depth of treatment, and
• introduces students to an appropriately modern, quantitative, and mechanistic molecular perspective of the natural world.

Programs exemplify a rigorous breadth of coverage through offering a significant diversity of courses, particularly at the in-depth level. Supplements that further articulate CPT expectations for coverage in different areas of chemistry are available on the CPT website (www.acs.org/cpt). Although it is impossible for CPT to consider the detailed content and course materials of every course in a given program in periodic reviews, CPT will evaluate program attributes that are believed to serve as critical indicators of undergraduate curriculum rigor. For foundation and in-depth courses, the depth and sophistication of the textbook used can serve as one proxy for course rigor. In addition, for in-depth courses, syllabi and exams will be thoroughly evaluated for evidence of course rigor. CPT will use in-depth course rigor as a proxy for rigor of the overall undergraduate program. The sophistication and depth of undergraduate research reports will be used as an additional indicator of program rigor.

Characteristics of Faculty Instructional Approaches in Rigorous Undergraduate Programs

The ability to offer a rigorous program depends on a competent faculty with modern disciplinary expertise in both chemistry content and in best practices in undergraduate chemistry instruction. Faculty should engage regularly in activities that sustain their vitality as professional chemists such as attendance at seminars, colloquia and professional meetings and workshops, and should consult on a continual basis the primary chemical literature.
Rigorous instructional strategies in course work:

- focus on creating learning environments that actively engage student participation,
- facilitate progressive development of student responsibility for learning throughout the curriculum,
- demand critical thinking and multi-step problem solving in daily activities,
- cultivate the development of an integrated understanding of chemistry throughout the curriculum, and
- require regular faculty feedback on student work with attention to correctness of student work, detailed commentary on language skills, and commentary on the precision and correct use of scientific language, chemical notation and representation, based on accepted norms of the profession.

Characteristics of Student Competencies in Rigorous Undergraduate Programs

A rigorous program fosters development of students who are actively engaged in and responsible for their own learning. Such students develop progressively throughout the curriculum the ability to

- analyze data and scientific arguments,
- synthesize and apply concepts from multiple sub-areas of chemistry,
- recognize the applicability of foundational and advanced concepts to new situations,
- solve multi-step complex problems, and
- communicate clearly answers and scientific reasoning in both written and oral forms.

Students in rigorous programs can demonstrate an integrated view of chemistry, drawing upon both appropriate quantitative reasoning as well as articulation of appropriate molecular mechanistic attributes of chemical processes.

Evidence for the development of these student competencies is embodied in the complexity of tasks that students undertake in formal classroom and laboratory course work as well as by the sophistication of undergraduate research activities in which students engage as documented in comprehensive written reports. Through their formal classroom course work, students should

- progressively develop the ability to complete assignments that require complex reasoning and higher-order problem-solving skills beyond simple algorithmic problem-solving and statements of declarative knowledge,
- demonstrate their ability to extend their conceptual understanding to chemical situations beyond those specifically discussed in the classroom,
- produce written work that exemplifies clarity of thought, independent thinking, and sound scientific analysis and reasoning, and
- demonstrate an appreciation of chemistry as a discipline built upon and advanced from a solid base of prior knowledge through effective use of the primary chemical literature.

In a rigorous formal laboratory course sequence, students should

- progressively develop effective and safe chemical laboratory skills that require use of the methods and instrumentation of modern chemistry,
- start with simple stepwise manipulations performed according to a prescribed sequence, but progress to activities that require decision-making about appropriate experimental design and data interpretation/analysis required to answer specific chemical questions, and
- produce organized, concise, and coherent descriptions and analysis of their experimental work through written and oral reports to which faculty provide detailed feedback.
Undergraduate research often provides a capstone experience in a rigorous program. A rigorous undergraduate research experience is one in which students demonstrate

- mastery of independent thought,
- self-direction of activities, and
- application of an integrated, quantitative, and molecularly mechanistic view of chemistry.

Characteristics of Assessments in Rigorous Undergraduate Programs

In evaluating program rigor, CPT will evaluate carefully summative assessments of student learning such as exams. Rigorous assessments are those that require students to demonstrate higher-order problem-solving and conceptual understanding skills. Appropriately rigorous exam formats include

- free response items,
- items requiring multi-step quantitative reasoning,
- items requiring demonstration of molecular mechanistic understanding of reaction pathways and chemical processes, and
- items that stretch students intellectually by requiring application of chemical concepts to new situations.

Exam items that require students to devise experiments to answer questions and that require articulation of chemical reasoning are excellent examples of rigorous assessment. Although one component of a rigorous exam might be multiple-choice items if special attention is paid to the construction of items that elucidate more than simple declarative knowledge, in general, CPT expects that rigorous assessments, especially those used for in-depth courses, will not rely heavily on a multiple-choice format. In addition to faculty-formulated exams, programs may also wish to consider using standardized ACS exams for assessment. Although such exams are necessarily multiple-choice in format, these exams provide a useful vehicle for national, normative-based assessment of student learning.

Strategies for Improvement of Program Rigor

Since appropriate rigor is a critical metric for ACS approval of an undergraduate chemistry program, programs should routinely assess the rigor of their undergraduate chemistry offerings. Should programs wish to further improve the rigor of their offerings, several strategies might be employed. Programs are encouraged to

- consult with colleagues at institutions of comparable size and mission, particularly those with excellent reputations for the production of well-trained undergraduates,
- consult the literature in chemical education for insight into rigorous and modern presentations of chemistry at the undergraduate level, and
- invite well-respected and knowledgeable chemists to consult on issues of undergraduate program rigor.

Attaining appropriate rigor in an undergraduate program is possible over time through careful attention to the programmatic details articulated above and by maintaining a watchful eye on modern developments in chemistry and chemical education.